ARM Crewed Segment AR&D Concept of Operations

For simplification, all discussion in this section assumes that the Multi-Purpose Crew Vehicle (MPCV), or Orion, will be the crewed vehicle that is performing the Rendezvous, Proximity Operations and Docking (RPOD) with the target vehicle. The target vehicle in this case, the Asteroid Redirect Vehicle (ARV) is the target vehicle while the MPCV (Orion) is the chaser vehicle. In this scenario, the target vehicle is assumed to be passive (no active translation burns or maneuvers), while the chaser is the active vehicle. Although the ARV will be passive, it will maintain its vehicle state (attitude and velocity) as dictated by the RPOD sequence.

Far Field (Rendezvous)

On the designated rendezvous and docking day, the Orion will compute the relative state vector by differencing the MCC uplinked ARV state vector to the Orion onboard state vector (which could also be updated by the uplinked MCC state vector estimate). The state vector differencing enables Orion to properly orient itself to enable RF communications as well as optical navigation. After RF communications is established between ARV and Orion, at around 100 km, the range and range-rate measurements are generated and provided to Orion's onboard relative navigation (RelNav) filter. Bearing measurements generated by optical sensors (visible and Infrared cameras) are combined with the RF based range and range-rate measurements in the RelNav filter. The bearing measurements (azimuth and elevation with respect to Orion) are generated to the centroid of the ARV. This approach affords the Orion the ability to perform far field (rendezvous) with little to no assistance from Earth based assets. As Orion's relative range approaches 10 to 5 km, the LIDAR is powered up and reaches steady state, operational temperature and is configured properly for the long-range acquisition. Throughout this phase of RPOD, the relative velocities between Orion and ARV are between 20 and 10 m/s, decreasing speed as Orion approaches ARV.

Near Field (Proximity Operations)

The next phase of RPOD, Proximity Operations, consists of LIDAR acquisition and generation of relative 3 degrees of freedom (3DOF) measurements: range, azimuth and elevation. The LIDAR 3DOF measurements provide a higher accuracy than the RF comm based range. The optical navigation based bearing measurements augment the LIDAR bearing measurements. The 3DOF measurements are processed by the RelNav filter to update the relative state estimation of ARV with respect to Orion. As Orion's relative range decreases, the ARV's size increases such that the optical navigation algorithms can use distinguishing features and LIDAR processing to prepare for relative 6 degrees of freedom (6DOF) state estimation. The measurement accuracies are expected to become more stringent the closer Orion is to ARV. Throughout this phase the relative velocity decreases from 1 m/s to 10 cm/s, while the range decreases from 5km to 20-30m.

Final Approach

The Final Approach phase requires Orion to translate and align to the ARV. The sensor measurements transition from relative 3DOF to relative 6DOF: outputting relative position and relative attitude of ARV with respect to Orion. The RelNav filter processes the measurements to determine a high accuracy navigation solution. During Final Approach, the relative velocity decreases from 10 cm/s to 0-5 cm/s, just prior to docking. At the start of Final Approach, a station-keeping maneuver (around 30 to 20m from ARV) may be implemented to ensure that the RelNav filter converges on a valid solution and finalize ARV and Orion docking mechanisms. The LIDAR provides the primary measurements, while the visible and IR cameras provide augmented measurements for the RelNav filter. Additionally, the visible cameras provide visual cues to the crew to monitor the docking progress.

Docking

At a range of approximately 5 m, Orion will execute a hold while the ARV is commanded to free drift by the ARV control center. After pressing in for final approach, MPCV will mode to free drift at first contact with the docking mechanism on the ARV, Following confirmation of free drift, the Orion-ARV stack will remain in free drift for approximately 20 minutes to allow the docking mechanism to transition from soft capture to hard mate. Following hard mate, the Orion RCS thrusters will be used to null stack rates and stabilize the stack in a post-docking attitude. Prelminary analysis indicates the induced docking torques will slew the vehicle up to 90 degrees out of the desired mated attitude. Once stable, the Orion RCS thrusters will be used to maneuver the stack back to its nominal attitude. The LIDAR and Optical cameras will provide the high accuracy measurements required to support docking with ARV. Relative velocity at contact should be between 0 to 5 cm/s (function of the docking mechanism and vehicles' mass properties).

The NASA Docking System (NDS) interface is constrained at docking by a 55°C maximum temperature difference across the passive and active halves of the mating interface. The rendezvous timeline outlined above may include a hold to allow the approaching MPCV to shadow the ARV docking interface to ensure the two halves meet this thermal constraint. The precise timing and duration of the hold will be defined through analysis of the expected shadowing of the ARV docking mechanism and the thermal environment of both mating halves.

Capture

Maintaining relative position, attitude in order to grapple. Once grapple is complete, then RelNav is complete, assuming that grapple is sufficient for mission success. Must be able to maintain close to 0 cm/s relative velocity while maintaining the active vehicle in the "capture box", essentially station-keeping.
Measurements: Relative 6DOF consisting of relative position and relative attitude
Sensor types:
LIDAR - 6DOF
Optical (visible, IR) – 6DOF based on target vehicle knowledge and image processing